Photon Detection System for DUNE low energy physics study and the demonstration of a few ns timing resolution using ProtoDUNE-SP PDS

Ajib Paudel (Fermilab)
On behalf of the DUNE collaboration
NuFACT, 2022

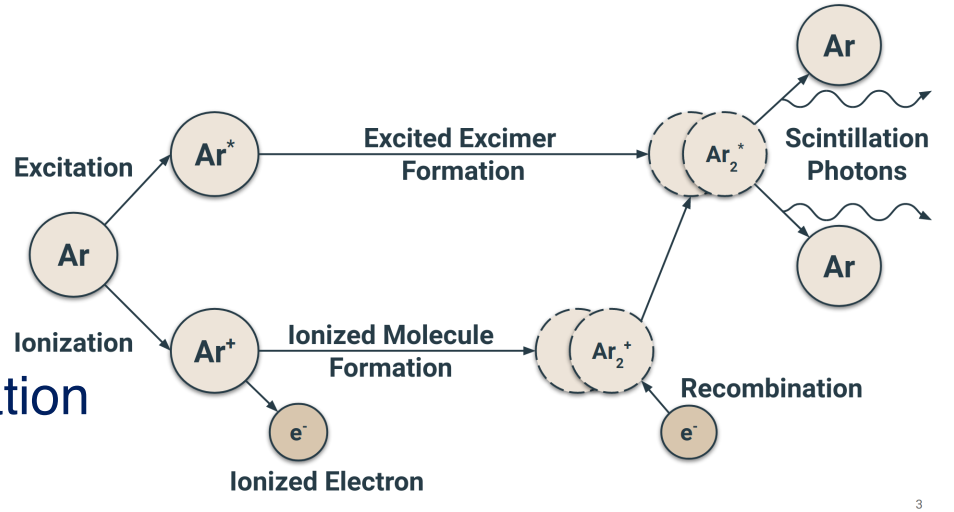
Outline

- **Photon Detection System (PDS) for liquid argon detectors**

- **PDS Timing Resolution Study**

- **PDS development to enhance DUNE Low energy Physics studies**

LAr scintillation

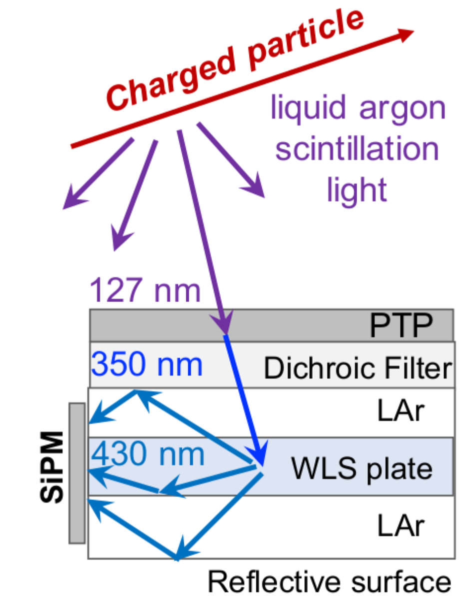


Schematic of scintillation light production in Ar (**arXiv:2002.03010)**

- A charged particle produces ionization as well as scintillation light in LAr
- MIPS Light yield ~ 25,000 photons/MeV at 500 V/cm
- Photon detectors are an integral part of LArTPC
- Using charge + light signals enhances the capabilities of a LArTPC
- Photon detectors provides t0, for precise event time (necessary for non-beam events)
- PDS has triggering and background rejection capabilities.

X-ARAPUCA technology for light detection

- Light traps used to enhance the photon detection efficiency.
- LAr scintillation light in VUV region shifted by using PTP deposited dichroic filter
- Inside the X-ARAPUCA a Wavelength Shifting Plate (WLS) is used to shift light to ~430 nm
- Silicon Photo Multipliers (SiPM) finally detects the photon signal



Not to scale.

Fig:X-ARAPUCA detector

Picture from: DUNE tdr

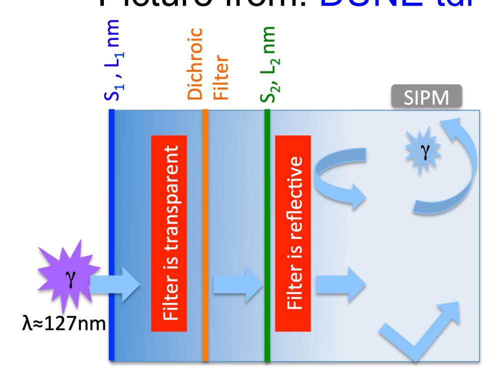


Fig:ARAPUCA detector (JINST)

 References: X-ARAPUCA

Photon Detection System Timing Resolution Study

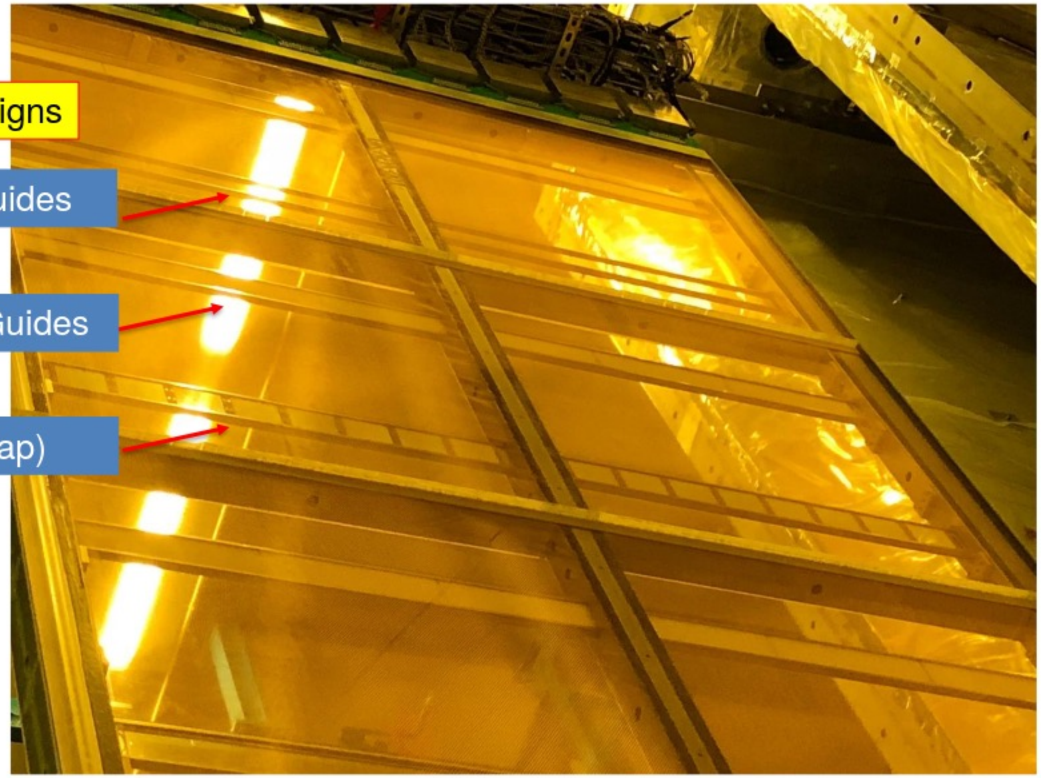
Technologies used in ProtoDUNE-SP PDS

PD Module Designs

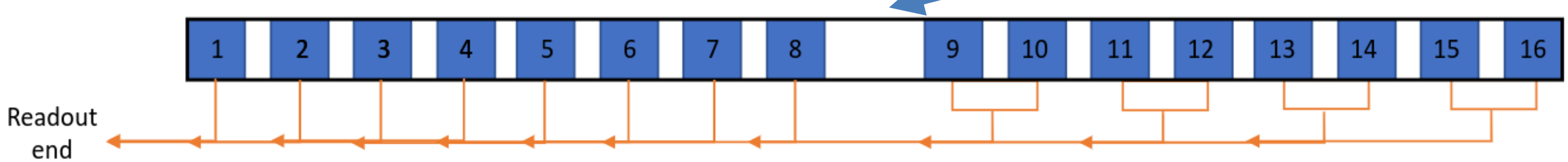
Dip-Coated Light Guides

Double-Shift Light Guides

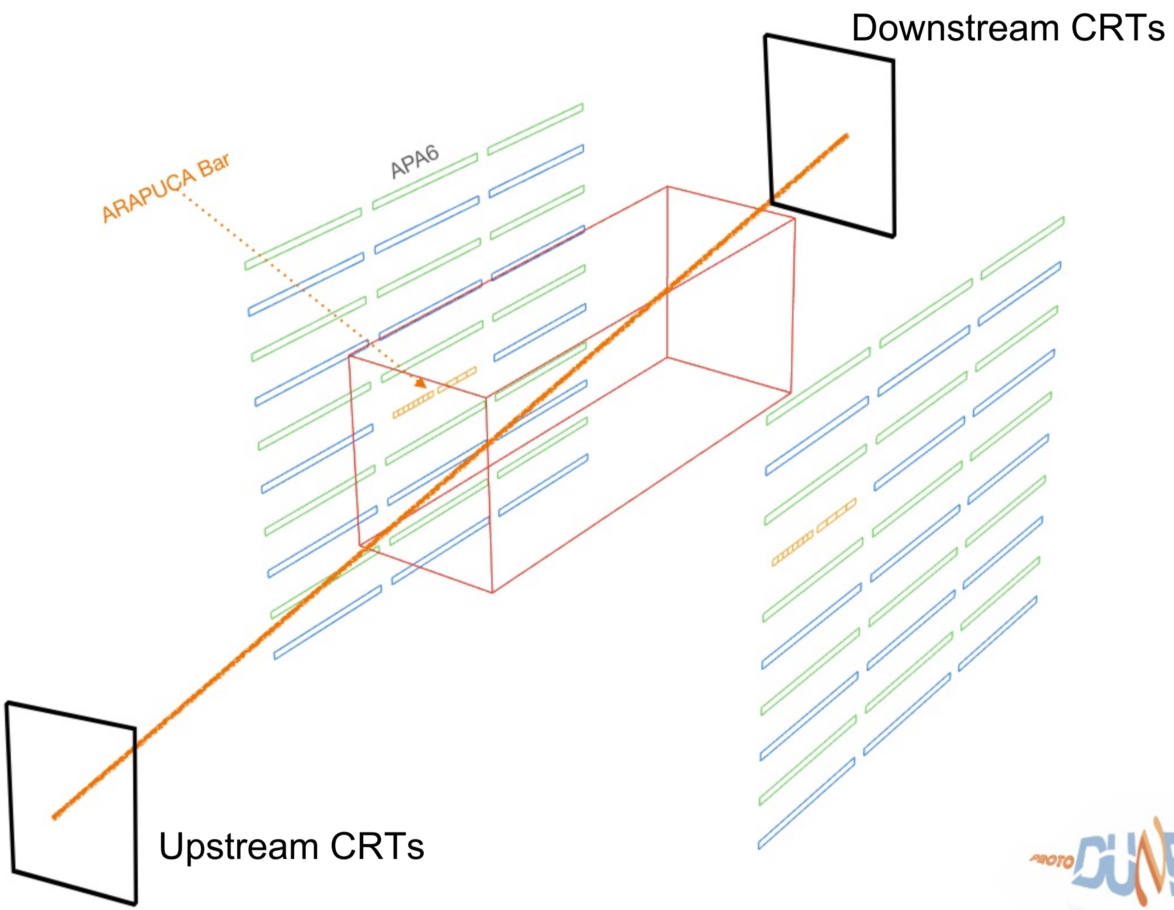
ARAPUCA (Light Trap)



12 ARAPUCA channels in APA6



Event Selection



protoDUNE-SP Cosmic Run

CRT-trigger: upstream-downstream (x,y)-hits in time coincidence

select sample of muon tracks ~parallel to ARAPUCA Bar in APA6 (at ~fixed distance, within small angular range)

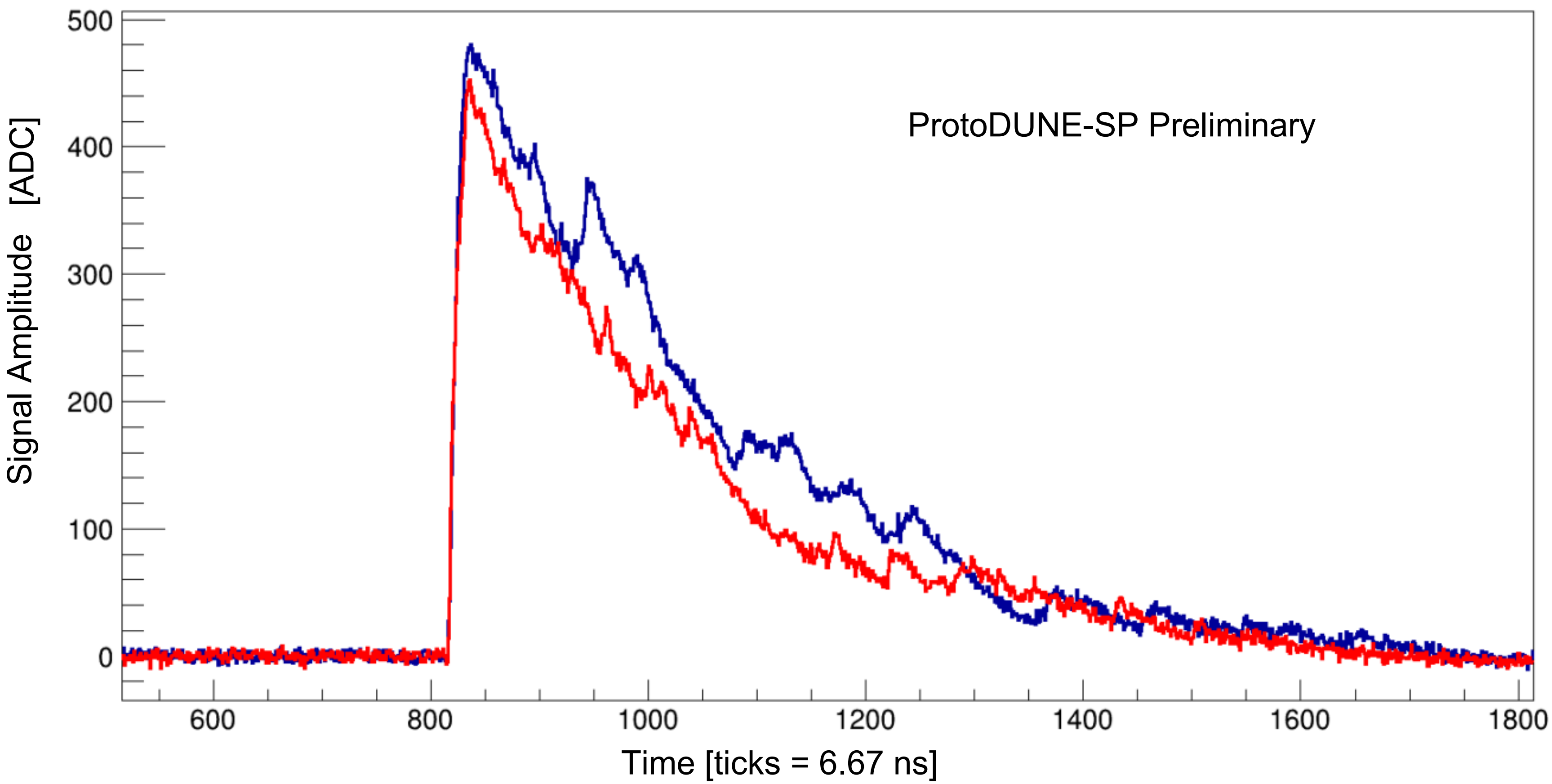
→ high, uniform illumination of ARAPUCA cells along the bar

→ ~equal arrival time of first photons onto optical surface of ARAPUCA cell

Further, I select only those events that have a TPC track matching with CRT flash.

Methodology:

Photons coming from the same track are examined by two separate ARAPUCA channels. Here I show signals for two nearby ARAPUCA channels.

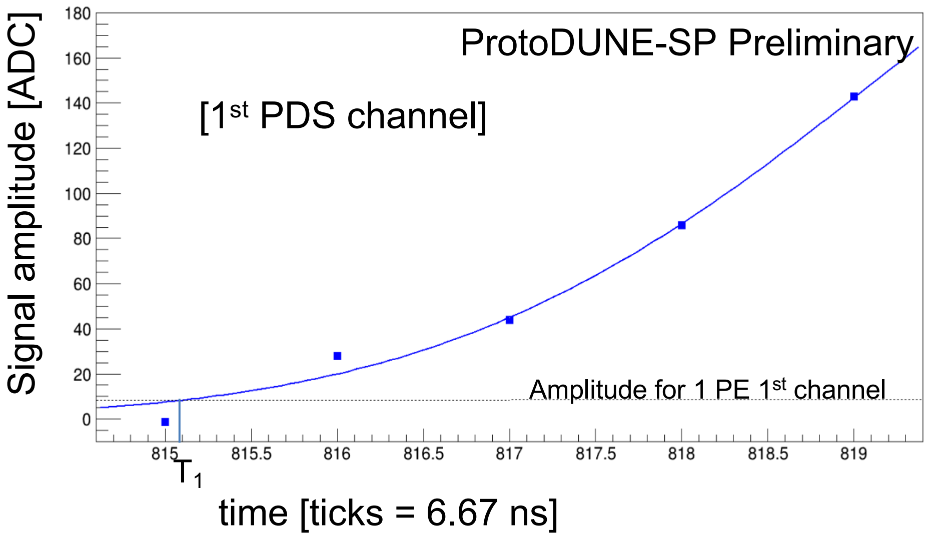


Methodology continued:

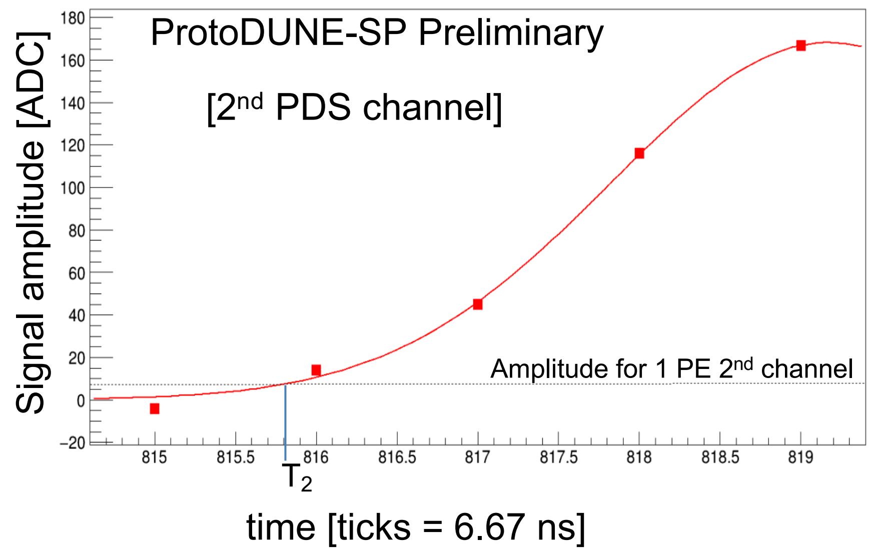
- Channels close to each other are chosen, such that first photon reaches both the channels at the same time.
- Difference in time (Δt) measured by the two channels depends on the intrinsic resolution of the detectors.
- A sampling frequency of 150 MHz was used for ProtoDUNE-SP PDS (which corresponds to a sampling time of 6.67 ns), which is the major factor affecting the timing resolution.
- To reduce the effect of sampling time, a fitting method is used for time measurement as described in next slide.

Find the time for the first photon:

Signal distribution selecting few points near the rising edge

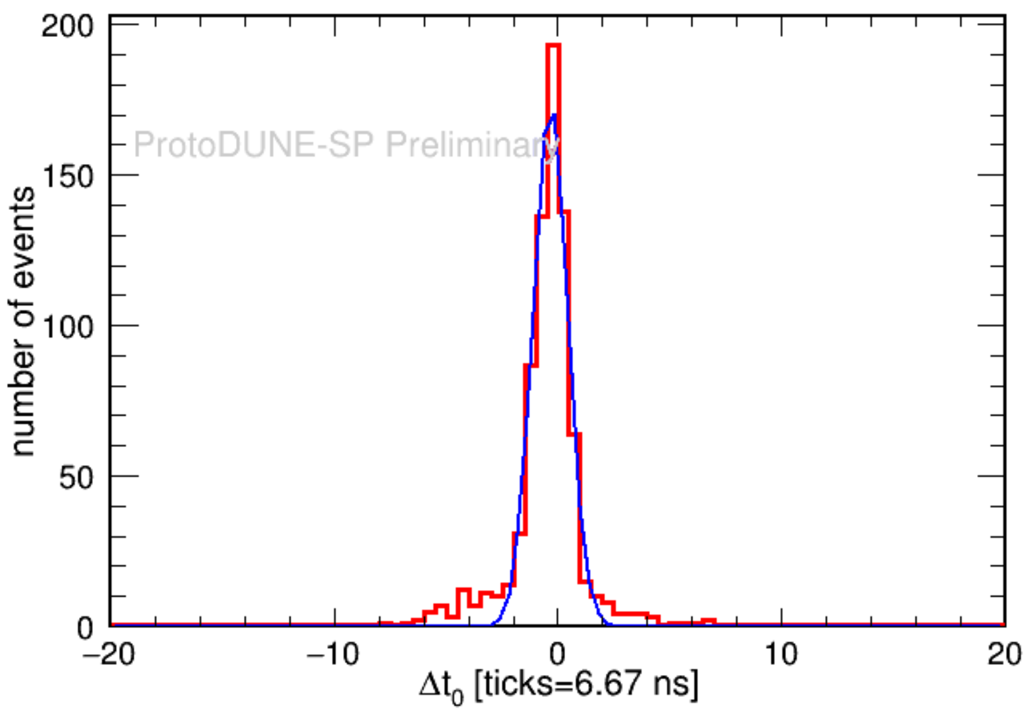


Signal distribution selecting few points near the rising edge



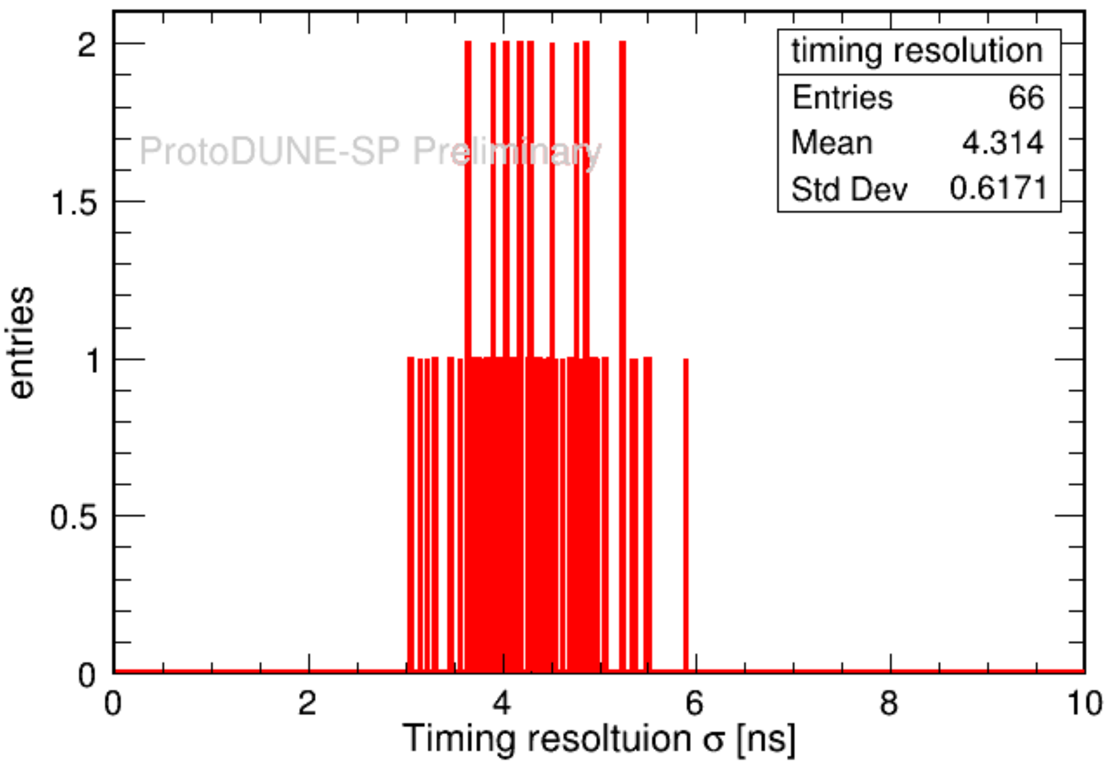
T_1 = time measured for 1st channel
T_2 = time measured for 2nd channel

Difference in time measured by two channels



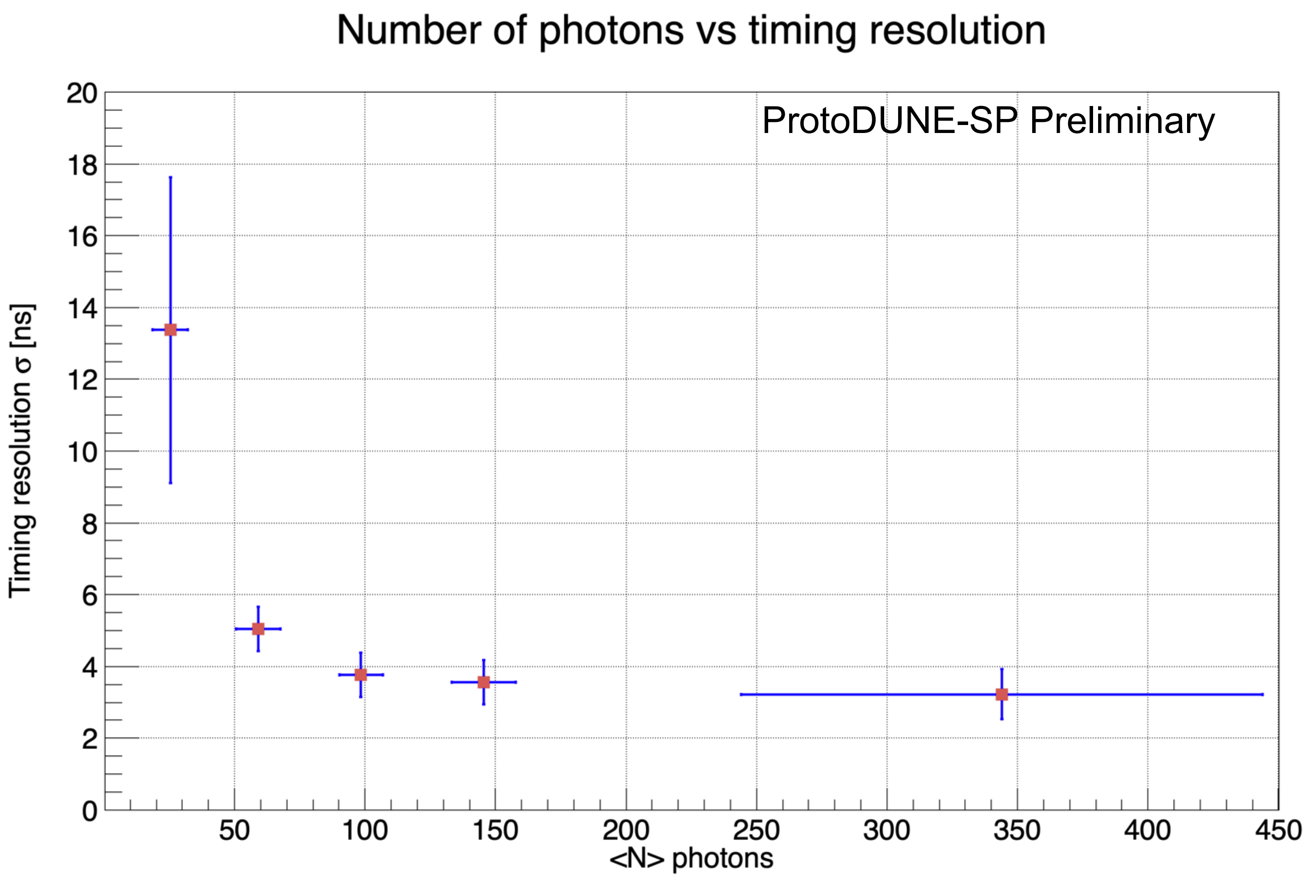
Measured timing resolution = sigma of fit/ $\sqrt{2}$ ~ 3.7 ns

Timing resolution measured for different ARAPUCA channel pairs:



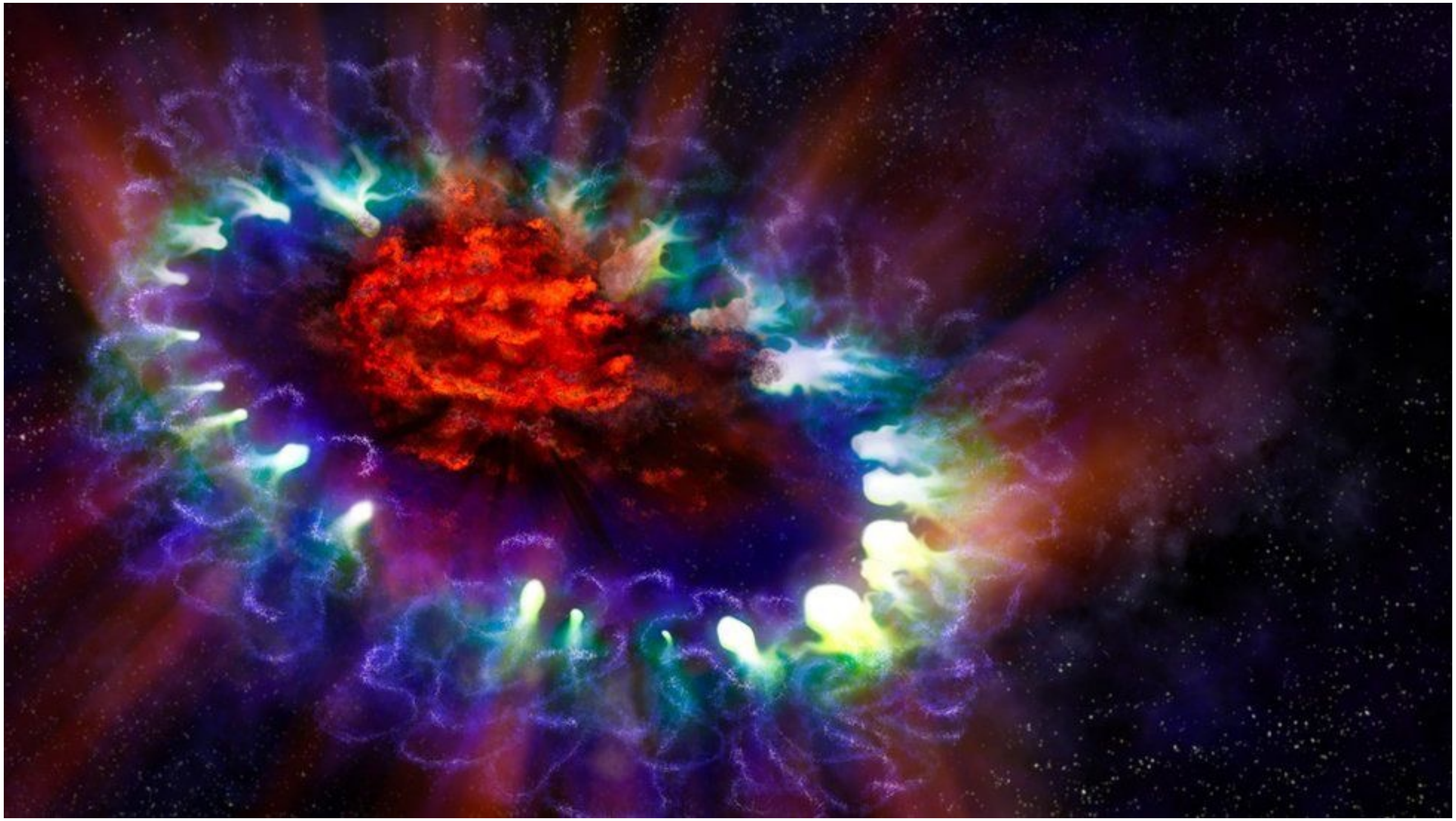
12 ARAPUCA channels in APA6 make 66 pairs

Dependence of timing resolution on photon numbers (<N>):



As the average number of photons increase, measured timing resolution value plateaus. At sufficiently high number of photons timing resolution -> 3 ns

DUNE LOW ENERGY PHYSICS



Picture taken from: [Supernova 'stream' in neutrino lab's sight]

DUNE Supernova Physics

- DUNE expects to observe neutrino-bursts from a core-collapse supernova during its lifetime.

- A few to few tens of MeV regime.

- LAr is uniquely sensitive to electron neutrino component

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

- Final state products appear as small tracks and blips requiring excellent energy resolution for precise neutrino energy reconstruction.

- Photon detectors may play an important role in triggering and calorimetric energy reconstruction of such events.

DUNE-FD2 (VD) PDS:

- Simulation studies for DUNE HD shows PDS energy resolution improves with increasing light yield (LY). (right plot)

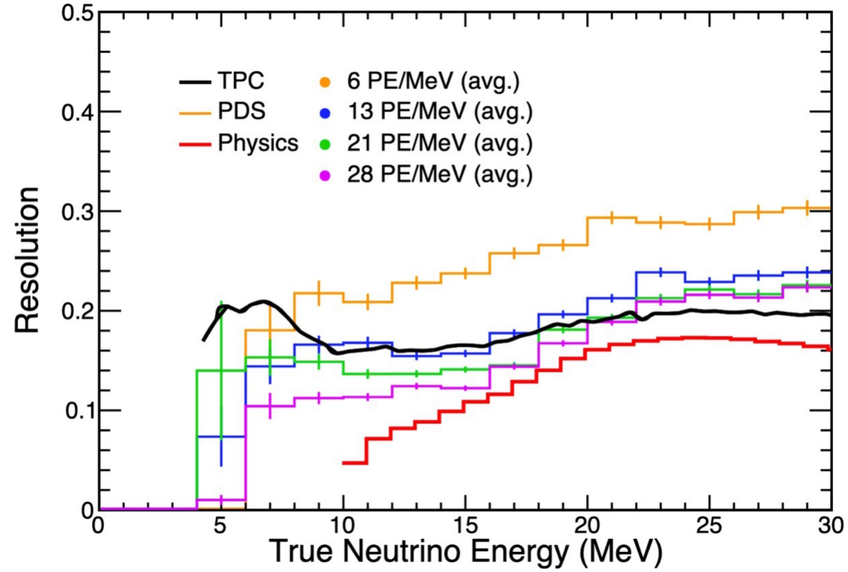
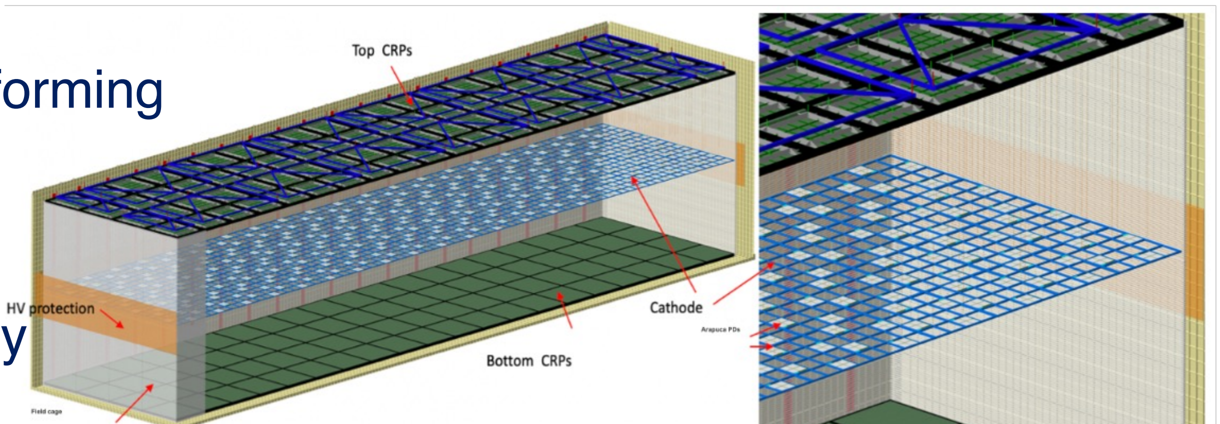


fig: DUNE HD (simulation) PDS vs TPC energy resolution (from DUNE tdr)

- To increase LY for DUNE FD2 (VD) PDS, we are planning to install PDS on top of High Voltage cathode surface as well as behind semi-transparent field cage.

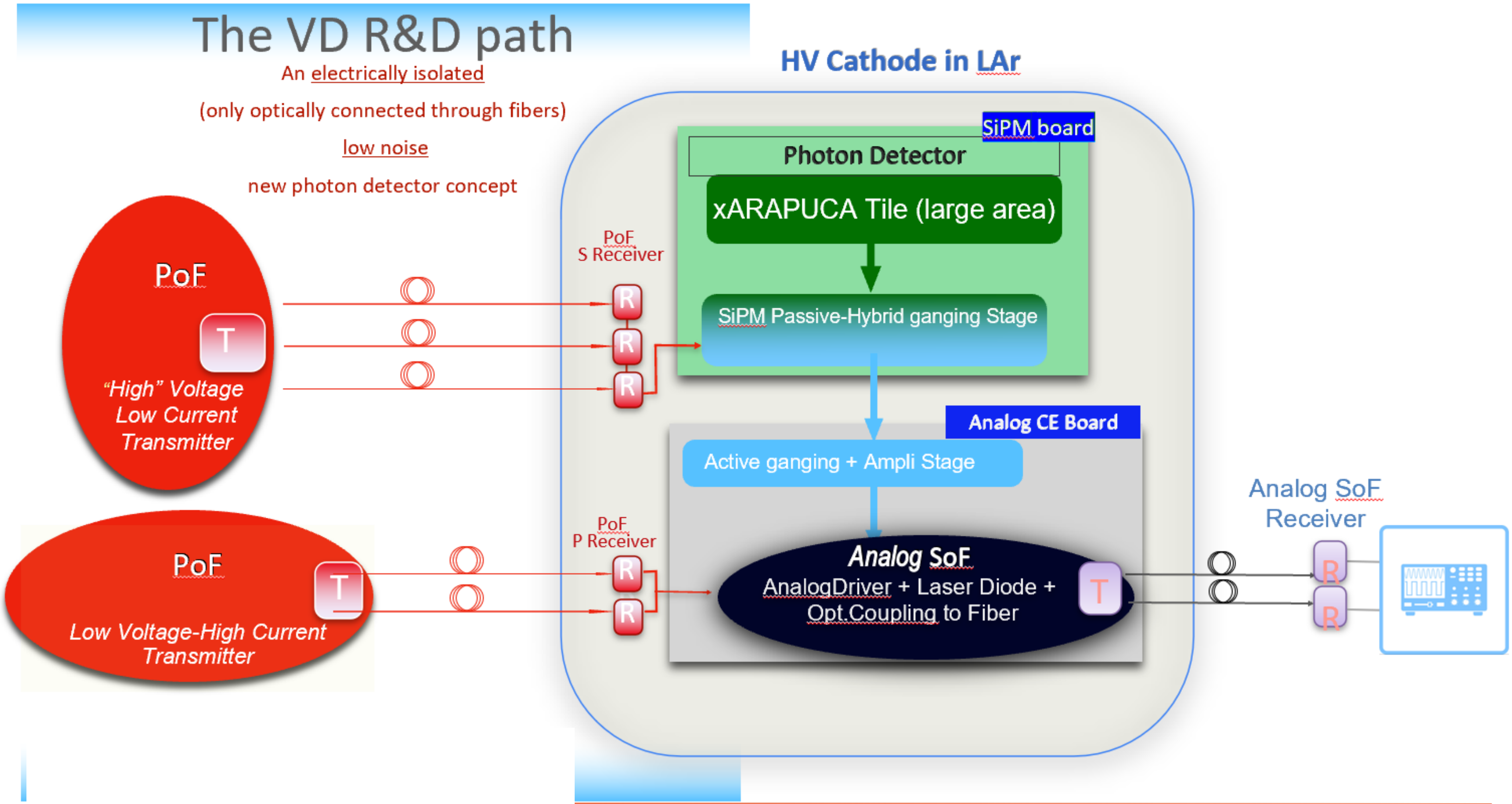
- Reflective CRPs are forming APAs

~4π PDS coverage is expected to improve energy resolution



DUNE FD2 (Vertical Drift detector schematic)

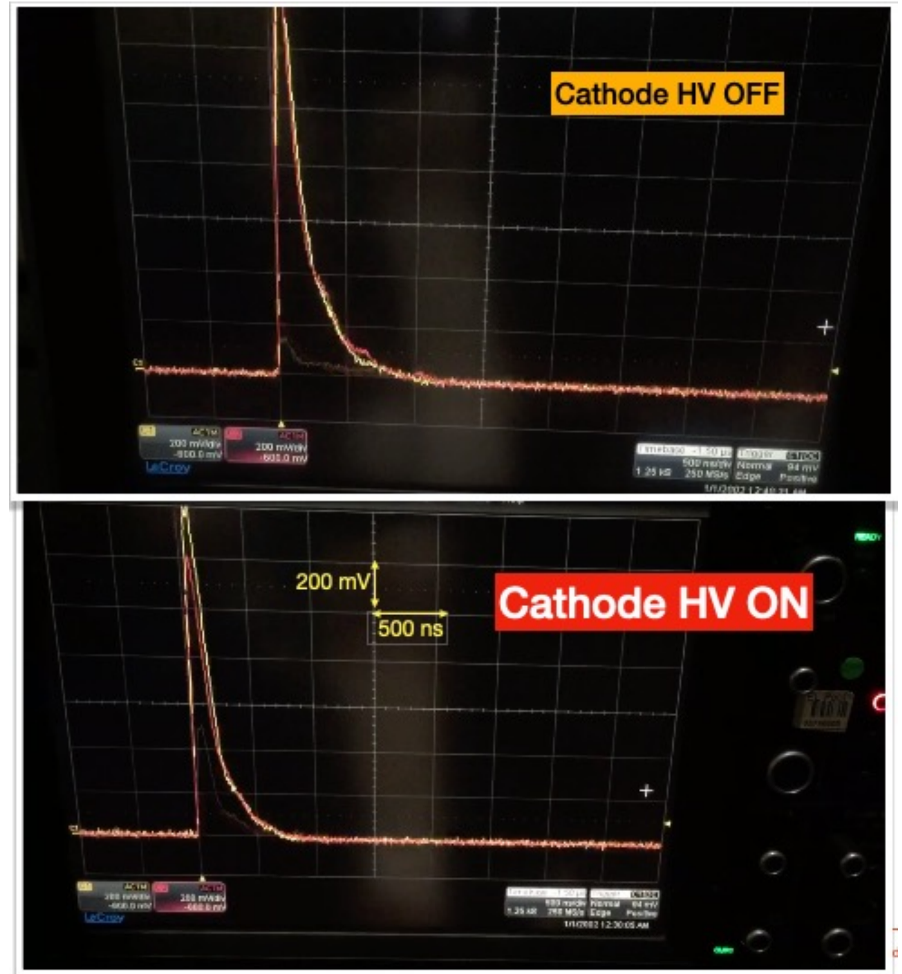
Novel technology for light collection at cathode maintainaing electrical isolation



PoF--> Power-over-fiber and SoF→ Signal-over-fiber

First Successful demonstration of PoF and SoF technology:

- The PoF and SoF technology successfully demonstrated on a prototype with a full-scale components at CERN.
- The figure on the right shows photon signals from cosmic muons collected with Cathode HV ON and OFF.
- R&D activities to further improve the signal quality and study long term stability (30+ yrs) are ongoing in various institutions across the globe.



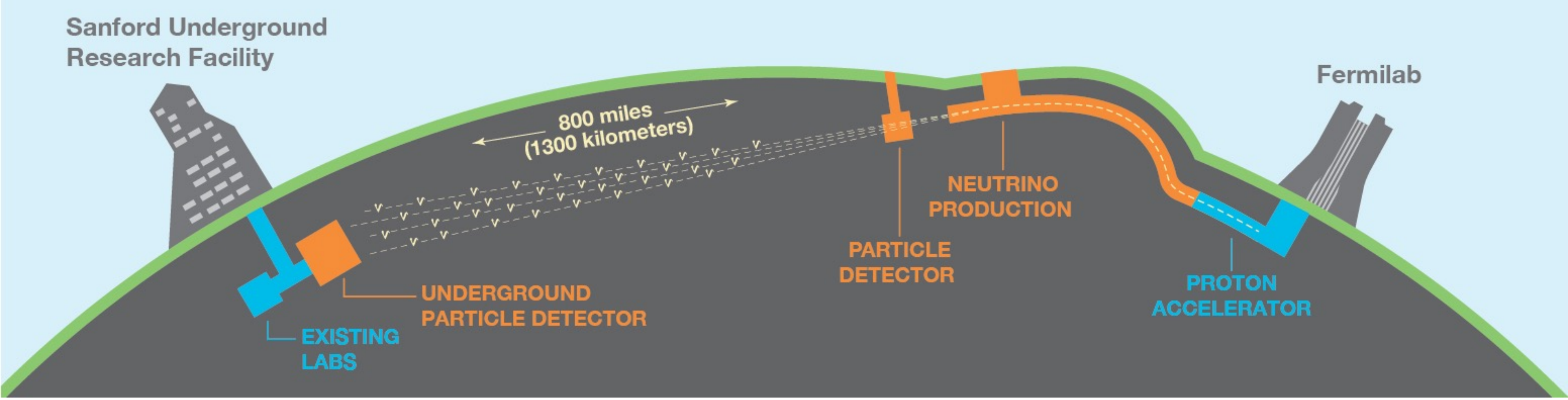
SUMMARY

- DUNE is a next generation neutrino detector using LAr technology.
- Photon Detection System has been shown to achieve ~3ns timing resolution using ProtoDUNE-SP data, which can be exploited for physics studies and background rejection.
- To get an excellent energy resolution at low energy DUNE FD module 2 is designed to have ~4π light coverage
- PDS planned to be placed on HV cathode surface.
- Electrical isolation will be maintained using novel PoF and SoF technology.

Thank you

BACK UP

Deep Underground Neutrino Experiment



Origin of matter: Exploring neutrino oscillations, CP violation. Are neutrinos the reasons world is made of matter?

Unification of forces: Proton decay and relation between stability of matter and Grand Unification theory.

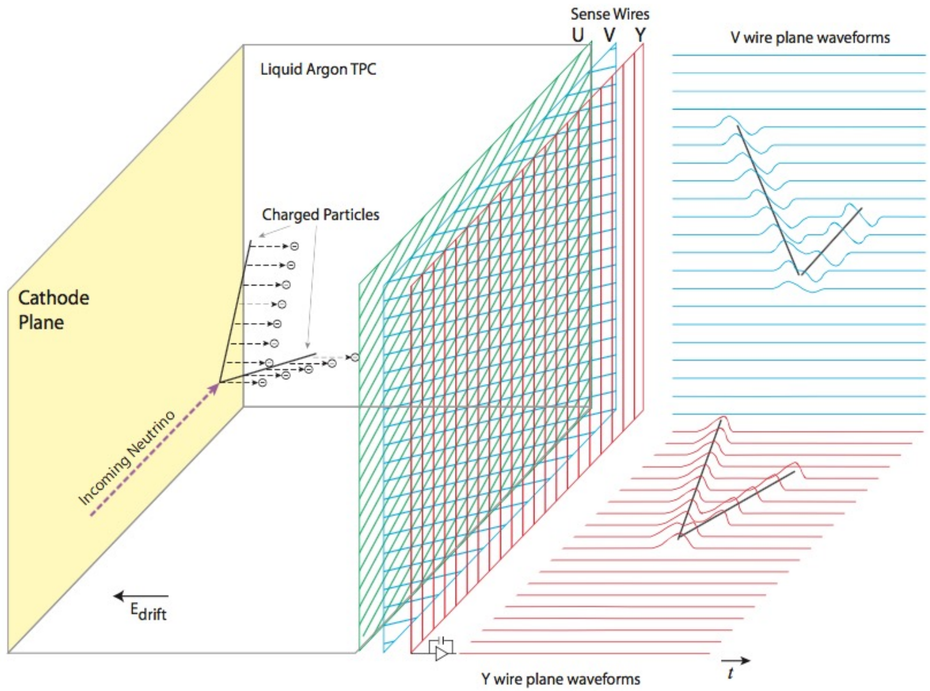
Black hole formation: Neutrinos from supernova burst help peer inside neutron star and black hole formation

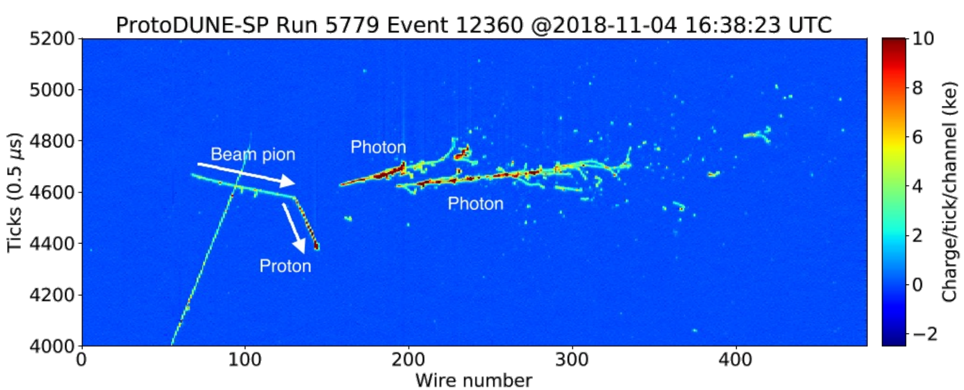
Reference: https://www.dunescience.org/

- **Prototyping production and installation procedures for DUNE-FD**
- **Validating design from perspective of basic detector performance**
- **Accumulating test-beam data to understand/calibrate response of detector to different particle species**
- **Demonstrating long term operational stability of the detector**

Major Goals

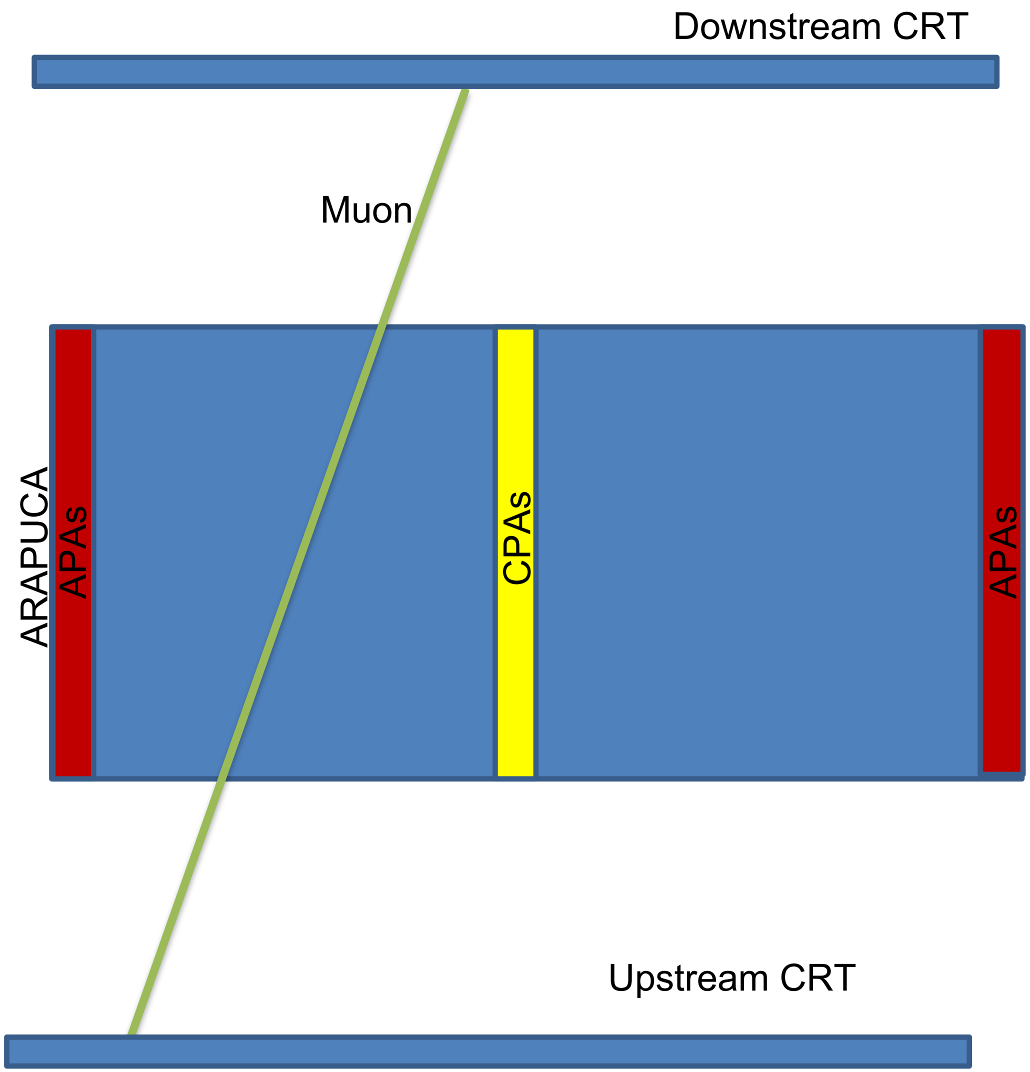
Liquid Argon Time Projection Chamber





- ➢ Charged particles produces electron-ion pairs and scintillation light.
- ➢ Electric field causes electrons to drift towards the anode/wire planes.
- ➢ Charge detected by wire planes as waveforms.
- ➢ Particle trajectory reconstructed based on the time and position of the waveform.
- ➢ Particle energy reconstructed based on charge deposited

PDS system are an integral part of LAr detectors collecting scintillation light.


Downstream CRT
Muon
ARAPUCA
APAs
CPAs
APAs
Upstream CRT

ProtoDUNE-SP Detector

- Largest Liquid Argon Time Projection Chamber (LArTPC) till date.
- 420 tons active mass of liquid Argon. 6 m X 6.9 m X 7.2 m dimension.
- 2 drift volumes of 3.6m drift length each.
- Started operation in Fall 2018.

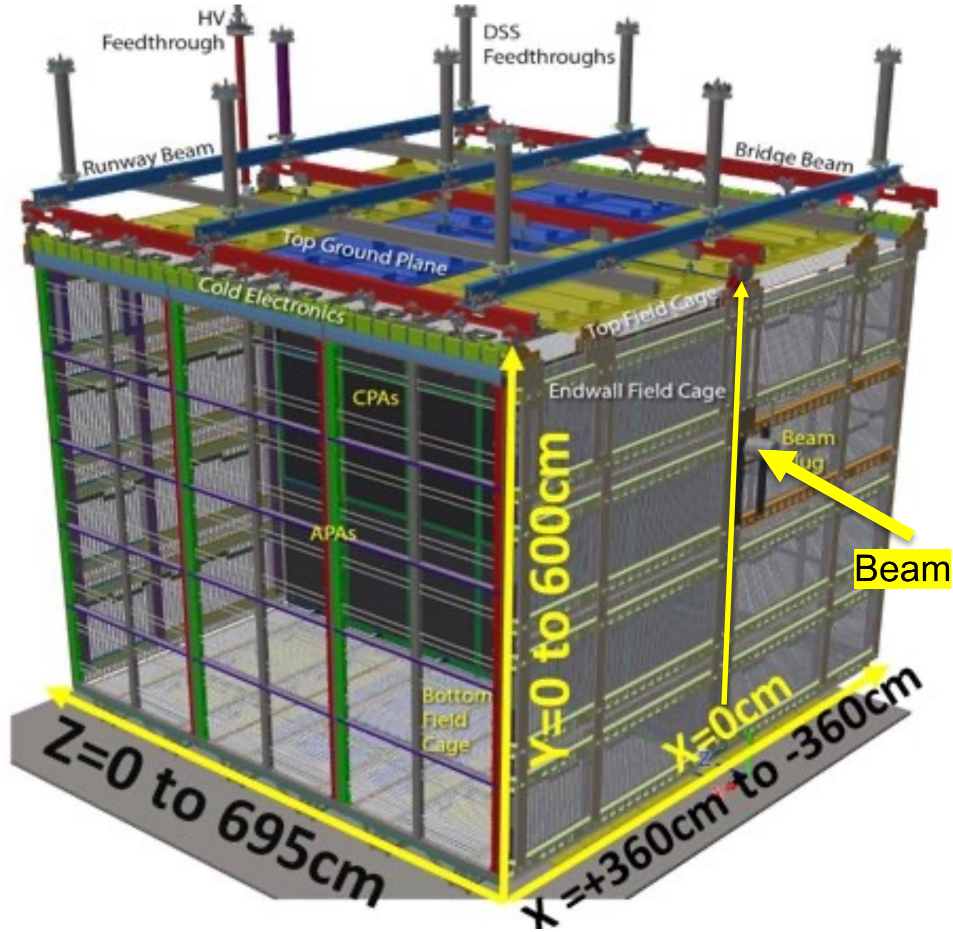


Fig: Components of ProtoDUNE-SP TPC